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(54) Method and apparatus for splicing optical fibers having different mode field diameters

(57) A fiber splicing apparatus of the present invention includes a support structure supporting the first and second optical fibers (112a,112b) such that ends of the fibers are aligned, and a laser emitting a laser beam (142) that impinges upon the ends of the first and second fibers such that the center of the laser beam is offset from the abutting ends of the fibers and impinges upon the first optical fiber a distance from the end of the first optical fiber, where the first optical fiber has a smaller mode field diameter (MFD) that the second fiber.

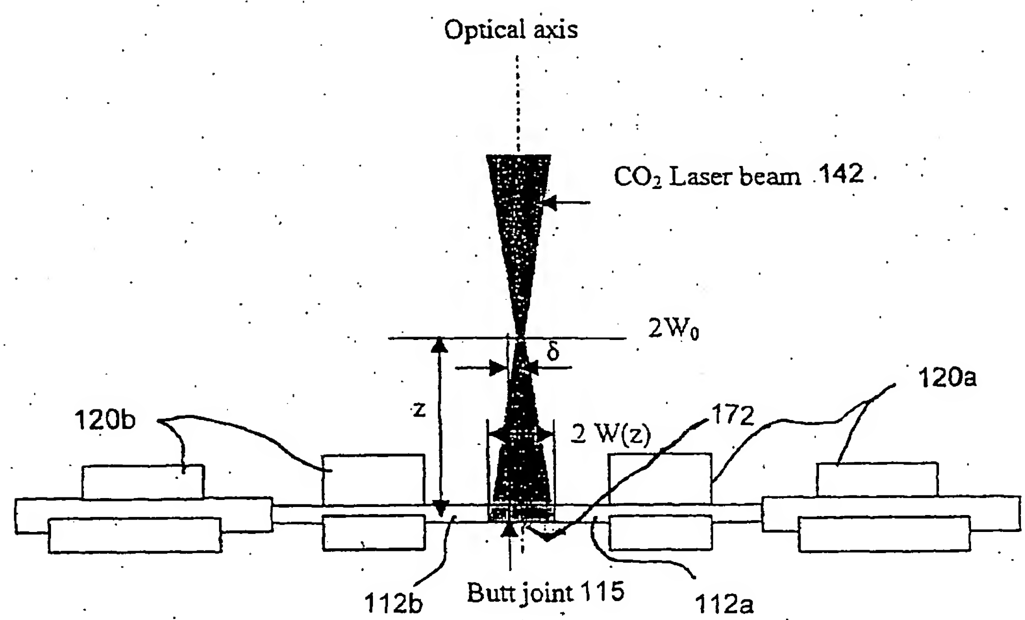


FIG. 2

Description

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The present invention generally relates to an apparatus for localized heating of optical fibers, and more particularly to an apparatus and method for splicing optical fibers having different mode field diameters.

2. Technical Background

[0002] Manufacturers and assemblers of optical networks, systems, and components often must splice together optical single-mode fibers, which may be identical fibers or non-identical fibers, that is, fibers having different mode field diameters (MFDs). When splicing together two fibers, the ends of the fibers are aligned and fused together by applying heat to the splicing area.

[0003] Any splice loss resulting from splicing together two identical fibers is principally due to misalignment (*i.e.*, longitudinal, transverse, angular, etc.) between the fibers. For two non-identical spliced fibers, loss results not only from misalignment of the fibers, but also from MFD mismatch between the fibers. Fiber misalignment is an extrinsic splice loss factor and can be reduced by using different alignment and cleaving techniques. MFD mismatch is an intrinsic splice loss factor. To reduce MFD mismatch, the MFD at the end of one of the fibers must be changed to match that of the other fiber. The MFD of a fiber may be increased by preheating the end of a first fiber having the smaller MFD thereby causing core dopants of the first fiber to diffuse into the cladding. After the end of the first fiber is preheated and the MFD expands to match the MFD of the second fiber, the ends of the first and second fibers are aligned and fused.

[0004] Splicing two non-identical fibers thus requires two steps. The first step is performed by preheating the first fiber end using a CO_2 laser. In the second step, the fibers are aligned and spliced together using conventional techniques, such as using an electric arc splicer or a CO_2 laser. Each of these two steps requires handling and aligning of the fibers in different apparatus. Such handling and alignment is generally performed manually and thus adds significantly to the time and cost of manufacturing an optical system, particularly one requiring many such splices.

[0005] The presently used techniques for changing the MFD of a fiber are not particularly accurate, and therefore, the resulting MFD mismatch introduces loss.

[0006] Therefore, there exists the need for a method and apparatus that reduces the time and cost involved in splicing together two non-identical fibers. Additionally, there exists the need for a technique for more accurately changing the MFD of a fiber and thereby reducing splice loss.

SUMMARY OF THE INVENTION

[0007] Accordingly, it is an aspect of the present invention to solve the above problems by providing a splicing method for splicing together two non-identical fibers in a single step thereby eliminating the need to handle and align fibers more than once and the need to provide or use more than one apparatus. Another aspect of the present invention is to more accurately control the MFD changes in the fibers and thereby obtain a splice exhibiting significantly less loss due to MFD mismatch. To achieve these and other aspects and advantages, the inventive method comprises the steps of supporting the two optical fibers such that the ends thereof are aligned, and projecting a laser beam from a laser onto the ends of the optical fibers such that the center of the laser beam impinges upon the first optical fiber a distance from the end of the first optical fiber and such that a portion of the laser beam simultaneously impinges upon the ends of the first and second optical fibers to heat and thereby fuse together the ends of the first and second fibers, where the first optical fiber has a smaller MFD than the second fiber.

[0008] Another aspect of the present invention is to provide a splicing apparatus that allows two non-identical fibers to be spliced together in a single step. To achieve these and other aspects and advantages, the splicing apparatus of the present invention comprises a support structure supporting the first and second optical fibers such that ends of the fibers are aligned, and a laser emitting a laser beam that impinges upon the ends of the first and second fibers such that the center of the laser beam is offset from the abutting ends of the fibers and impinges upon the first optical fiber a distance from the end of the first optical fiber, where the first optical fiber has a smaller MFD than the second fiber.

[0009] Additional features and advantages of the invention will be set forth in the detailed description which follows and will be apparent to those skilled in the art from the description or recognized by practicing the invention as described in the following description together with reference to the claims and appended drawings.

[0010] It is to be understood that the foregoing description is exemplary of the invention only and is intended to provide an overview for the understanding of the nature and character of the invention as it is defined by the claims. The accompanying drawings are included to provide a further understanding of the invention and are incorporated and constitute part of this specification. The drawings illustrate various features and embodiments of the invention which, together with their description serve to explain the principals and operation of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] In the drawings:

Fig. 1 is a schematic diagram illustrating a portion of the splicing apparatus constructed in accordance with the present invention viewed perspectively;

Fig. 2 is a schematic diagram illustrating a portion of the splicing apparatus constructed in accordance with the present invention viewed from the side;

Fig. 3 is a plot of an examplary laser beam spot energy distribution produced by the splicing apparatus of the present invention;

Fig. 4A is a cross-sectional view of two abutting fibers having different MFDs;

Fig. 4B is a cross-sectional view of the fibers shown in Fig. 4A with a laser beam spot from the inventive splicing apparatus projected thereon;

Fig. 4C is a cross-sectional view of the fibers shown in Fig. 4A after splicing;

Fig. 5 is an optical/electrical diagram in block form of the splicing apparatus constructed in accordance with the present invention;

Fig. 6A is a front elevational view of an optical beamsplitter used in the splicing apparatus shown in Fig. 5; and

Fig. 6B is a side elevational view of the beamsplitter shown in Fig. 6A.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0012] Reference will now be made in detail to the present preferred embodiment of the invention, an example of which is illustrated in the accompanying drawings. Wherever possible, the same reference numerals will be used throughout the drawings to refer to the same or like parts.

[0013] As described above, the present invention pertains to an apparatus and method for splicing together the ends of a first optical fiber and a second optical fiber where the first optical fiber has a smaller MFD than the second fiber. In general, the method includes the steps of supporting the two optical fibers such that the ends thereof are aligned, and projecting a laser beam from a laser onto the ends of the two optical fibers such that the center of the laser beam impinges upon the first optical fiber a distance from the end of the first optical fiber and such that a portion of the laser beam simultaneously impinges upon the ends of the first and second optical fibers to heat and thereby fuse together the ends of the first and second fibers. As described below, the laser beam spot may have a Gaussian energy distribution such that the laser beam spot heats the first fiber to a higher temperature than the second fiber. By heating the first fiber with the smaller MFD to a higher temperature, the core dopants of the first fiber diffuse into the cladding to a much greater extent than those in the second fiber so that the MFDs become substantially equal at the butt joint of the two fibers. By also exposing the butt joint of the two fibers to a portion of the beam spot, the two fiber ends fuse together. Thus, two fibers having different MFDs may be spliced together using a single exposure step thereby significantly reducing manufacturing time and cost.

[0014] Having generally described the principles of the inventive method, an apparatus for carrying forth the inventive method is described below.

[0015] Figs. 1, 2, and 5 show a splicing apparatus constructed in accordance with the present invention. In general, the splicing apparatus is constructed in a manner similar to the splicing apparatus disclosed in commonly-owned European Patent Application No. 00400815.7, filed on March 23, 2000, with the exception of the modifications described below that allow that apparatus to be used to splice fibers having different MFDs.

[0016] The splicing apparatus includes a support including support members 120a and 120b for supporting two optical fibers 112a and 112b such that the ends thereof, 114a and 114b respectively, are aligned. The region in which fiber ends 114a and 114b abut one another is referred to as splicing area 115. As shown in Fig. 1, fibers 112a and 112b are cantilevered from support members 120a and 120b. The cantilever distance *b* is much shorter than the cantilever distance of a conventional electric splicer. Thus, the distance between support members 120a and 120b of the inventive splicing apparatus is less than about 6 mm and is preferably about 1 mm. By thus reducing the cantilever distance *b* to about 0.5 mm, one may more readily align fiber ends 114a and 114b. Because of the reduced cantilever, fibers 112a and 112b are less likely to bend significantly when ends 114a and 114b are pushed together, and the intrinsic curl of fibers 112a and 112b is less likely to result in misalignment of the fiber ends.

[0017] To enable support members 120a and 120b to be spaced more closely together, the inventive splicing apparatus utilizes a laser beam 142 to heat and fuse fiber ends 114a and 114b instead of a plasma field such as produced by electrodes of an electric arc splicer. The laser beam 142 may be focussed using a focussing lens 148 to a small spot at splicing area 115 with a high degree of consistency and precision. This focussed spot generally exhibits a Gaussian energy distribution, such as that shown in Fig. 3.

[0018] As mentioned above, the present invention exploits the fact that the laser beam spot has a Gaussian energy distribution by offsetting the center of the spot relative to the butt joint of fiber ends 114a and 114b when fibers 112a and 112b have different MFDs. For example, assuming first fiber 112a has a smaller MFD than second fiber 112b, as illustrated in Fig. 4A, the center 172 of the laser beam spot 170 (Fig. 4B) is offset from the butt joint of fiber ends 114a and 114b by a distance δ along the central axis of first fiber 112a. Due to the Gaussian energy distribution at laser beam spot 170, the portion of first fiber 112a proximate the butt joint is heated to a higher temperature than second fiber 112b. As noted above, heating the first fiber at a higher temperature

ond optical fibers such that ends of the fibers are aligned; and
a laser emitting a laser beam that impinges upon the ends of the first and second fibers such that the center of the laser beam is offset from the abutting ends of the fibers and impinges upon the first optical fiber a distance from the end of the first optical fiber.

8. The apparatus of claim 7, wherein said support structure supporting the first and second optical fibers such that ends of the fibers overlap.

9. The apparatus of claim 7, wherein said laser is a CO_2 laser.

10. The apparatus of claim 7 and further including:

an optical modulator positioned to receive and selectively modulate the intensity of the laser beam to project a modulated laser beam along a first optical path that terminates at the region of the first and second optical fibers to be heated; and
a control loop that monitors the intensity of the modulated laser beam and controls said optical modulator to regulate the intensity of the modulated laser beam in response to the monitored intensity level.

11. The apparatus of claim 7, wherein said support structure includes two support members each of which supports one of the two optical fibers, said support members being spaced less than 6 mm apart.

12. The apparatus of claim 7, wherein said support includes two support members each of which supports one of the two optical fibers, said support members being spaced about 1 mm apart.

13. The apparatus of claim 7, wherein the laser beam spot has a Gaussian energy distribution.

14. The apparatus of claim 7, wherein the laser beam spot is at least about 500 μm.

15. The apparatus of claim 7, wherein the laser beam spot is about 1 mm.

16. The apparatus of claim 7, wherein the center of the laser beam spot is offset about 30 μm from the butt joint of the two fibers.

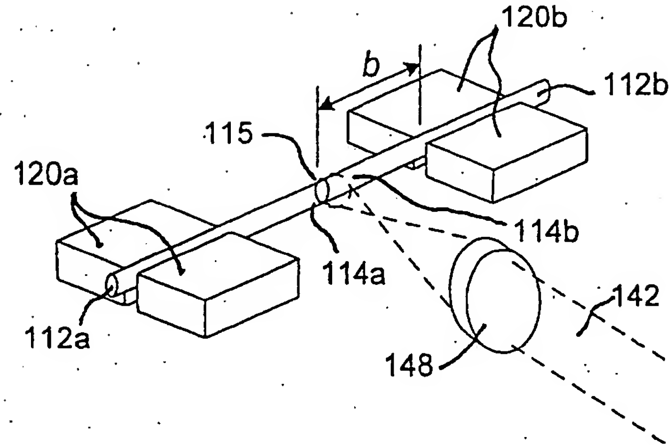

120b
b
112b
115
120a
114b
114a
142
112a
148

FIG. 1

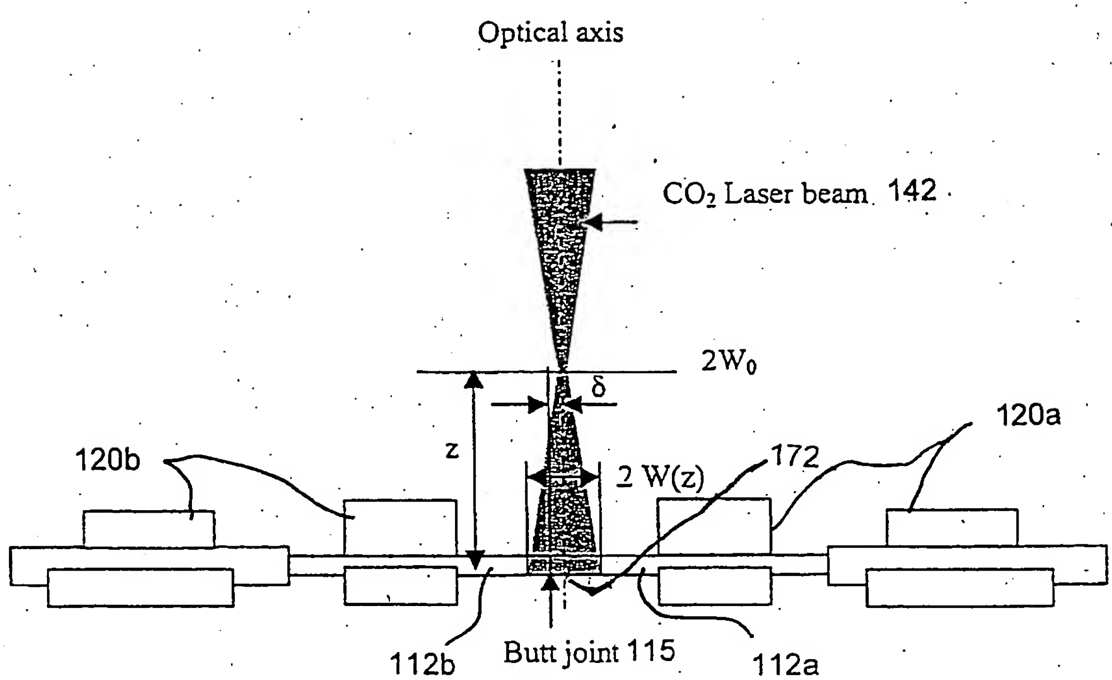

Optical axis
CO_2 Laser beam 142
$2W_0$
δ
120a
z
120b
172
2 W(z)
112b
Butt joint 115
112a

FIG. 2

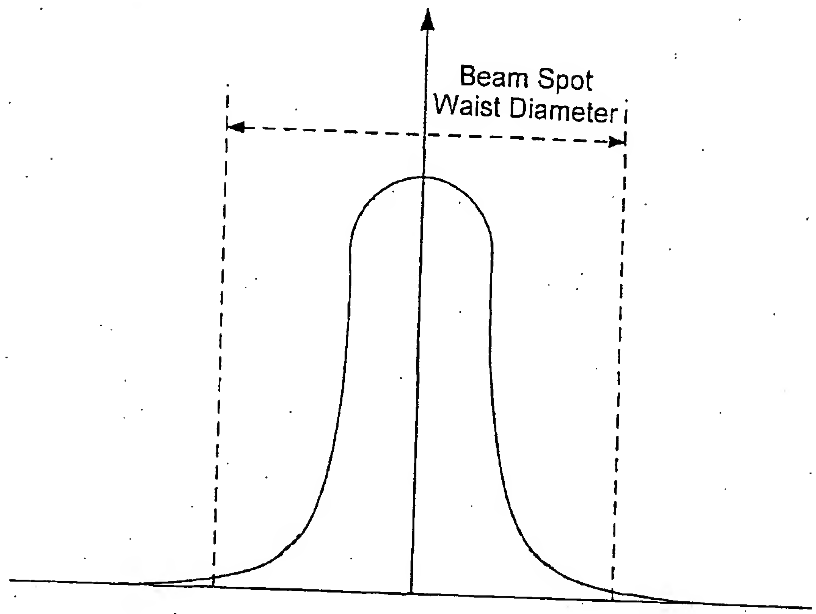
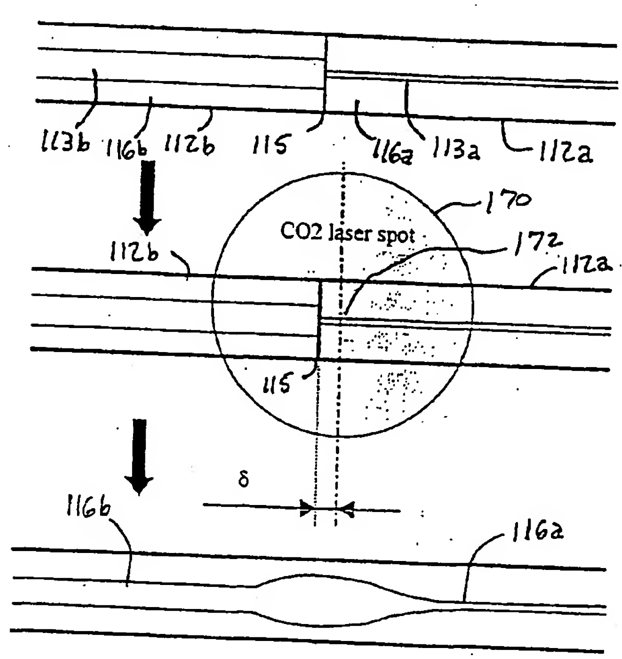


FIG. 3

FIG. 4A

FIG. 4B

FIG. 4C



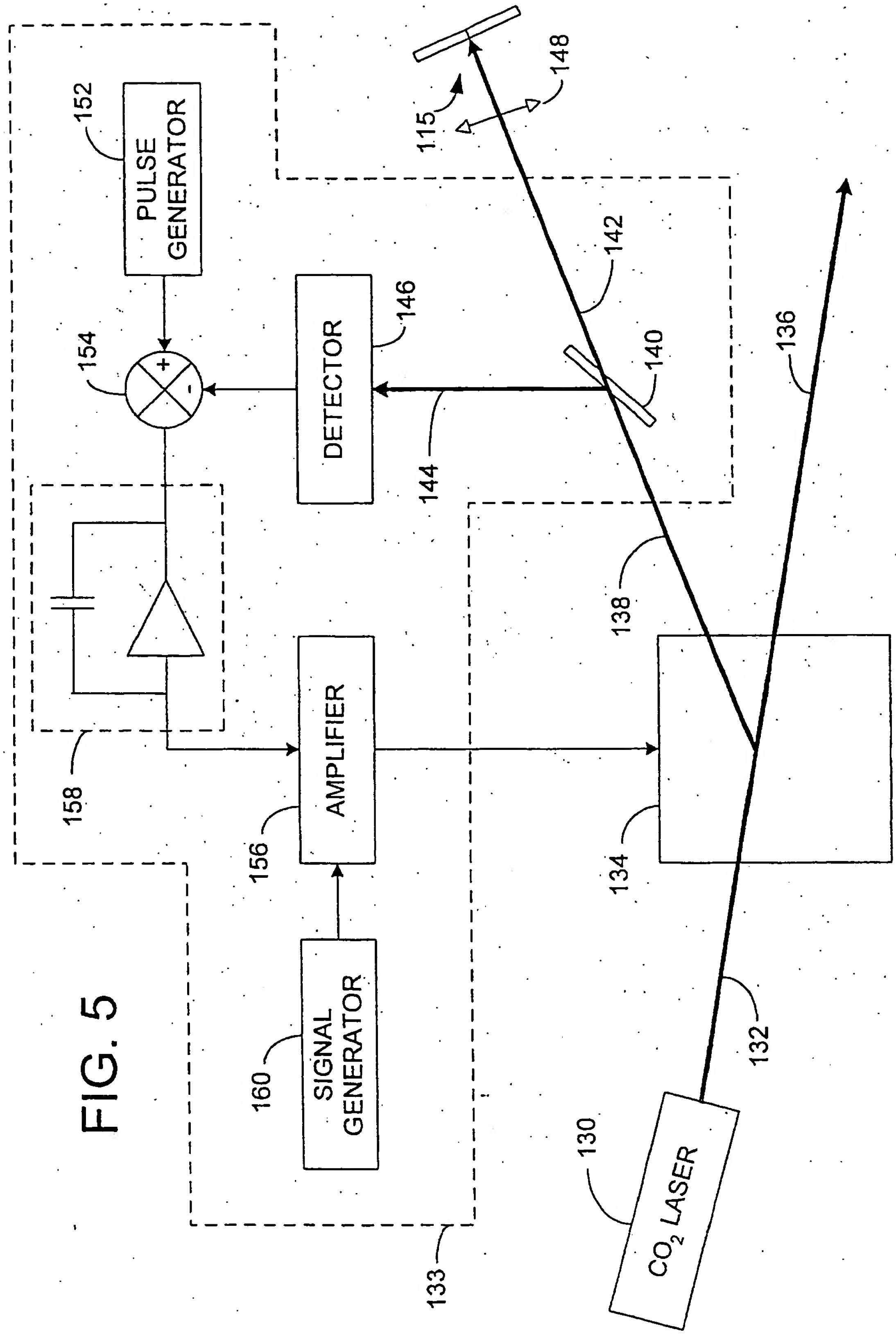

PULSE GENERATOR
152
154
+
-
DETECTOR
146
144
140
142
148
115
136
138
158
AMPLIFIER
156
134
SIGNAL GENERATOR
160
133
132
130
CO_2 LASER

FIG. 5

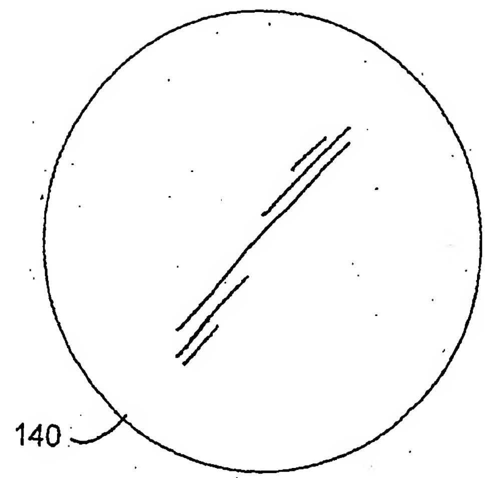


FIG. 6A

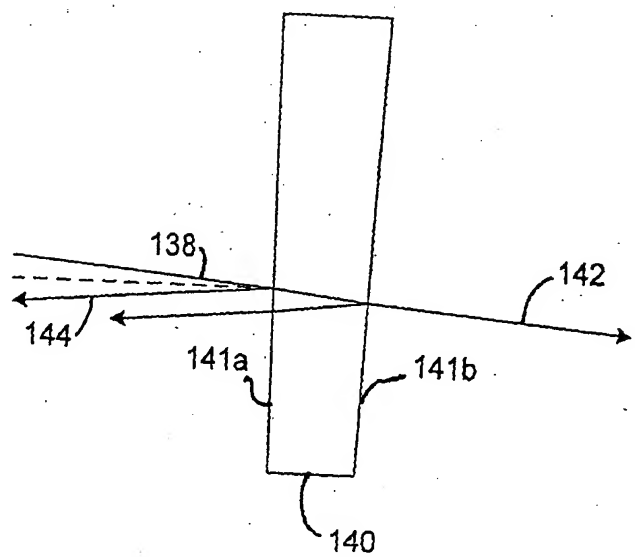


FIG. 6B

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EUROPEAN SEARCH REPORT

Application Number
EP 00 40 2080

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	20 December 2000	Mathyssek, K

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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